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by

Beatrice J. Selwyn
Thomas H. Stock
Robert J. Hardy
Frances A. Chan

University of Texas School of Public Health at Houston
Houston, Texas

Daniel E. Jenkins
Baylor College of Medicine
Houston, Texas

Dennis J. Kotchmar
Robert S. Chapman
Health Effects Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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EPA Project Officer
Dennis J. Kotchmar

HEALTH EFFECTS RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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HEALTH EFFECTS OF AMBIENT OZONE EXPOSURE IN VIGOROUSLY EXERCISING ADULTS

Beatrice J. Selwyn, Sc.D.,¹

Thomas H. Stock, Ph.D.,¹ Robert J. Hardy, Ph.D.,¹

Frances A. Chan, M.S.,¹ Daniel E. Jenkins, M.D.,²

Dennis J. Kotchmar, M.D.,³ Robert S. Chapman, M.D.³

¹University of Texas School of Public Health at Houston

²Baylor College of Medicine, Houston, TX

³U.S. Environmental Protection Agency, North Carolina

The purpose of the analysis was to examine the association of changes in ambient ozone concentrations with changes in the pulmonary function (PFT) of healthy adults after exercising vigorously outdoors. During May-October, 1981, 24 community residents (men and women) ran three miles twice a week some time between 4:30 and 6:30 PM at a high school track near Houston, Texas. An air monitoring trailer stood beside the track and monitored environmental variables continuously. The continuously measured environmental variables in this analysis (ozone, temperature, and relative humidity) were averaged over 15 minute intervals. Standard forced expiratory maneuvers were performed before and after each run. Exercise exertion was standardized.

Linear regression analysis revealed that the change in PFT was significantly associated with change in ozone concentration between .004 and .135 ppm. Increasing concentrations of ozone resulted in decreased PFT values.

The interrelation between ozone, temperature, and especially relative humidity meant that when temperature and relative humidity were both controlled in a multiple variable regression analysis, the association of change in ozone concentration and change in pulmonary function lost significance, but the direction of change remained towards a decrement.

The study findings suggest that outdoor aerobic exercise during periods of increased ambient ozone concentrations up to .135 ppm produces at least a short-term decrease in pulmonary function.

Introduction

Environmental chamber studies have documented the physiological effects of short-term exposure to specific concentrations of ozone on human pulmonary function, but the relation of these findings to community exposures is unclear. The purpose of the analysis reported here was to examine the association of changes in ambient ozone concentrations with changes in the pulmonary function of healthy adults after exercising vigorously. This epidemiologic study resembles a natural experiment since it occurred out-of-doors with community residents running in a manner necessary to maintain cardiovascular health while exposed to natural variations in ozone concentrations occurring during summer months.

Research indicates that short-term pulmonary effects of ambient ozone exposure are clearly detectable in exercising persons.^{2,3,4} As the level of exercise rises, the combination of increased minute volume and breathing by mouth results in an increased total pollution dose delivered to the respiratory tract. Theoretically, a large percentage of the daily dose of ozone could be acquired during vigorous exercise.

Materials and Methods

In this study twenty-four healthy adults ran at least twice a week for six months during May through October, 1981, on a track located about 30 miles southeast of downtown Houston, Texas. Physiological measurements were made before and after each exercise period since the change in physiology was the outcome variable of interest. Constituents of the air were measured continuously at the run site throughout the study.

To fulfill the study objective we recruited through letter and radio campaigns, a group of 50 adults, who typified runners exercising for health maintenance purposes. Twenty-seven subjects were physically healthy, were used to running in the ambient conditions of summer, and were "maintenance runners," that is, they usually ran at least 10 miles per week regularly. Each subject served as his/her own control. The subjects did not take drugs that might affect responses to ozone (example: thyroid supplements) but were allowed to continue with whatever vitamins they regularly took (38% took Vitamin E and 58% took Vitamin C). To objectively verify healthy physical condition and exercise training all subjects received physical examinations, chest x-rays, lung function tests, and maximum oxygen uptake tests.

Of the 27 acceptable study subjects, 24 completed the six month study. Three dropped out for job-related reasons. The 24 white subjects included 6 women and 18 men, ranged in age from 29 to 47 years and were characteristic of college graduates in urban middle class society who run to "keep in shape" (Table I).

Every effort was made to reduce the number of variables that might independently influence pulmonary function. Subjects ran the same distance (three miles) at a similar level of effort. Level of effort was controlled by heart rate, since it was not possible in this study to monitor respiratory rates during the run. Subjects kept their heart rates between 75% and 90% of their heart rate at maximum oxygen uptake. An Exersentry device (Respironics, Inc., Monroe, PA; use of this product does not constitute endorsement by either EPA or the University of Texas) monitored heart rates -

continuously during the run, cuing runners through auditory signals for the minimum and maximum heart rates.

Two exercise days per week were assigned to runners to prevent their choosing run days according to perceived environmental conditions. An average of 28 runs per runner resulted. Outside aerobic exercise for 24 hours before a study run was discouraged to minimize possible interdependence of exposures.

Runners exercised in all weather conditions except rain. No runner nor field staff member had access to specific values for climate or pollution concentrations for the run site. Although the daily maximum ozone concentration usually occurred in the early afternoon, exercise was scheduled between 4 PM and 7 PM to accomodate the work schedules of study subjects.

Continuous monitoring of ambient concentrations of ozone, other criteria pollutants and meteorological variables was performed for the six-month study period at a monitoring station located at the edge of the running track, in accord with the relevant U.S. Environmental Protection Agency siting criteria.⁵ Standard EPA reference or equivalent instruments were used to measure all criteria pollutants, e.g., chemiluminescence analyzers for ozone. The site used for this study was one of those described in the accompanying report (Contant et al., "Estimation of individual ozone exposures using microenvironment-based measurements") and used the same quality assurance programs.

Continuously recorded environmental measurements were averaged over 15-minute intervals during the time of running (4-7 PM). Since most runners completed their runs in less than one hour, the usual one-hour-average value would not accurately reflect their ozone exposures. Every run performance required more than 15 minutes, with the shortest run time recorded at 18 minutes (the average variation in run time was 7 minutes). Also, during the late afternoon, ozone concentrations fluctuated considerably, even within an hour, and the use of 15-minute average values captured this variability. An example of the variations in ozone concentrations during one run day appears in Figure 1, with actual run times displayed for four different runners. Since runners ran through more than one 15-minute averaging period, a method was developed to estimate exposure, using 15-minute average concentrations.

The intent was to estimate peak exposure for each runner during each running performance, using the highest 15-minute average values recorded during his/her run time. These 15-minute average values were combined into a weighted average which estimated the exposure received during the 15 minutes of his/her run when ozone concentrations were highest. Figure 2 gives an illustration of the calculation of 15-minute average maximum ozone exposure for two runners who performed during different intervals on the same run day.

This analysis does not include other criteria pollutants such as sulfur dioxide, nitrogen dioxide or carbon monoxide, because these pollutants were present in low concentrations (Table II) and have not been shown to alter the effect of ozone on the respiratory tract under conditions of this study.² Data on fine inhalable particulates were recorded as 12 hour averages. The difficulty of relating a 12-hour average value for one variable to 15-minute average values for other variables has precluded the inclusion of particulates in the analysis.

Pulmonary function tests were performed at the run site using Ohio Medical Products rolling seal spirometers. Measures included forced vital capacity (FVC), forced expiratory volume at 1 second (FEV₁), forced expiratory flow in the middle portion of the curve (FEF_{25-75%}), and forced expiratory flow rate between the first 0.2 and 1.2 liters of expired air (FEF_{2-1.2}). Subjects performed three acceptable pulmonary function maneuvers during each session, and using a standardized protocol, the two best curves were selected on the basis of FVC and FEV_{1.0} and averaged. Two sets of PFT measures are used in this analysis for each runner at each exercise session: one made immediately prior to running and another at 15 minutes after the run.

The actual difference in pulmonary function (calculated as post-run pulmonary function minus pre-run pulmonary function, or Δ pf) represents the effect of exposure to ambient air during a run. In the first analysis of Δ pf and ozone the scatter plots for each runner revealed linear associations between Δ pf and ozone concentration. One linear regression coefficient for each runner's set of run days measured the change of Δ pf with increasing ozone concentrations for each PFT. The regression coefficients were averaged over all runners and a t-test was used to indicate whether the group's average slope (regression coefficient) differed significantly from zero.

Thereafter, each runner's set of Δ pf results were regressed on ozone concentration with adjustment for the effects of temperature and of relative humidity using a multiple linear regression model. The variances of individual partial regression coefficients for ozone concentration varied among the runners, so a weighted average was computed for the group using an iterative technique reported by Korn and Whittemore.⁶ The Z-score indicated statistical significance using the 5% level of significance.

Results

The concentration of ozone to which runners were exposed averaged .047 ppm during the study with a maximum concentration of .135 ppm (Table III). The current National Ambient Air Quality Standard (NAAQS) for ozone of a maximum hourly average of .12 ppm was reached or exceeded on only three days during the 4-7 PM period.

Temperature exposures averaged 85°F during the runs (Table III) and temperature remained in the eighties for most of the study, while relative humidity exposures averaged 62% during the runs and varied more during the study than temperature. Exposure during the run occurred at some time between 4-6:30 PM. During those hours of the day ozone concentration had a small negative correlation with temperature while relative humidity correlated in a strongly negative fashion with ozone for all runners (Table IV).

Exposure

Linear regression analysis of Δ pf on individually weighted 15-minute maximum ozone exposures for each runner resulted in negative summary regression coefficients for all PFTs (Table V). For FEV_{1.0}, FEF_{25-75%}, and FEF_{2-1.2} the change is significant. (-B means that the post run PFT is lower than the pre-run PFT). Thus, for this group of runners, the change in PFT was toward larger decrements in post-run PFT with increased ambient ozone concentrations.

The second set of analyses revolved around temperature and relative humidity. It showed that Δ pf decreased significantly with decreased levels of temperature and relative humidity. Analysis of Δ pf and ozone adjusted for temperature alone did not change the significant negative association of Δ pf with ozone concentration. However, adjustment for relative humidity alone rendered the association of Δ pf and ozone statistically nonsignificant, although the direction of the changes in Δ pf remained negative. The variation in the regression coefficients increased greatly with adjustment for relative humidity.

Removing the linear effects of both temperature and relative humidity in a weighted regression analysis reduced the absolute value of the regression coefficients for FEV_{1.0}, FEF₂₅₋₇₅, and FEF_{2-1.2} with ozone concentration by more than half (Table VI). All three of these PFTs maintained negative coefficients, while the regression coefficient for FVC became positive after adjustment.

The effect of adjusting simultaneously for temperature and relative humidity while regressing Δ pf on the 15-minute weighted average for ozone concentration during the runs varied among the runners. As an example, regression coefficients for each runner were plotted against each runner's adjusted regression coefficient for FEV_{1.0} (Figure 3). The superimposed line represents where all points should lie if adjustment had no effect on the original regression coefficient. For FEV_{1.0}, 10 regression coefficients were lower after adjustment and 11 higher, and two runners have greatly increased coefficients after adjustment for temperature and relative humidity with accompanying larger standard deviations of the coefficients. These two runners had extreme values, but no reason could be found to remove them from the data set. This same phenomenon occurred for each PFT, but different runners were involved.

Discussion

Regression coefficients indicate that Δ pf is significantly associated with increasing ambient ozone concentration under a maximum of .135 ppm when averaged across all 24 subjects in this study. After adjusting for relative humidity these changes were no longer statistically significant, probably due to the confounding occurrence of decreasing relative humidity with increasing ozone (the median correlation coefficient was -0.423), although a real lack of association is possible. The problem in interpretation comes from the way the environmental variables relate to one another and to pulmonary function.

Ozone forms part of a mix of substances in ambient air that require care when attempting to analyze separate effects. If two factors occur simultaneously and both have legitimate effects on PFT, controlling for one factor may remove the effect of the other factor. This may be the case here. At the time of day (4-7 PM) used in this study, humidity and ozone concentrations co-varied in a strongly negative fashion. Both decreasing relative humidity and an increasing concentration of ozone are associated with a significant decrease in PFT post-run, and the relation of relative humidity to PFT and to ozone serves to confound the analysis. Stacy et al. suggested on the basis of chamber studies that heat, humidity, and exercise alone are unlikely to produce lowered PFTs. The concentration of ozone is the main variable that affects the magnitude of the pulmonary function decrement. This is a complex issue and it does seem important to evaluate the results both with and without adjustment since if there is no control of temperature and humidity in the analysis, the effect of ozone on Δ pf could

be over-estimated. On the other hand, by adjusting for relative humidity, the effect of ozone is probably underestimated.

The regression coefficient unadjusted for temperature and relative humidity suggests that for every .001 ppm increase in ozone there is a decrease of .4 ml in $FEV_{1.0}$. Extrapolating these data as linear to below a concentration of .2 ppm ozone (where studies show a dramatically accelerated decrease in PFT occurs^{2,9} and assuming a 20 minute average exercise period, at .16 ppm of ozone, there would be a decrease of 64 ml in $FEV_{1.0}$. To compare with findings in Avol et al.² where an exercise period of one hour is used, the decrement apparent in 20 minutes in our study is assumed to increase threefold to arrive at 60 minutes of exercise--yielding an estimated decrease of 192 ml in $FEV_{1.0}$ after 60 minutes of vigorous exercise at an ozone concentration of .16 ppm.^{1.0} Avol et al.² obtained a 235 ml decrease at this concentration of pure ozone in a chamber, and a decrease of 205 ml with ambient ozone concentration estimated between .08 and .16 ppm. Our study's extrapolated decrement in $FEV_{1.0}$ at .12 ppm is similar to that reported by McDonnell et al.⁹ from their chamber study, 216 ml versus 210 ml respectively. Given the assumptions in the extrapolation of the linear regression coefficient, our findings are within the range of other studies that have evaluated the effect of lower concentrations of ozone.

Many Americans exercise vigorously outdoors every day. Public health professionals advocate exercise as a means of maintaining good health and many professional athletic performances occur weekly. During the time of vigorous (aerobic) exercise, individuals inhale large amounts of air, usually through the mouth, thereby losing the protective mechanisms of nose breathing, and constituents of the air may be taken into the lower respiratory system. Fortunately, the body's natural defense system can effectively deal with most substances. However, exercise increases the pulmonary uptake of ozone and excessive ozone concentrations compromise pulmonary function. In agreement with chamber study results, the direction of the change in pulmonary function in this study is toward a decrement in $FEV_{1.0}$, FEF_{25-75} , and FEF_{2-12} after running while exposed to increasing concentrations of ozone. Although the long-term effects of ozone exposure are unknown, the findings here suggest that outdoor aerobic exercise during periods with ambient conditions such as those observed here (ambient ozone concentrations no higher than .135 ppm) produces at least a short-term decrease in pulmonary function.

REFERENCES

1. L. J. Folinsbee, S. M. Horvath, P. B. Raven, et al., "Influence of exercise and heat stress on pulmonary function during ozone exposure." J. Appl. Physiol., 43: 409-13 (1977).
2. E. L. Avol, W. S. Linn, T. G. Venet, et al., "Comparative respiratory effects of ozone and ambient oxidant pollution exposure during heavy exercise," JAPCA 34: 804-9 (1984).
3. W. B. McCafferty, Air Pollution and Athletic Performance. Illinois: Charles C. Thomas (1981).
4. W. S. Linn, E. L. Avol, and J. D. Hackney, "Effects of ambient oxidant pollutants on humans: a movable environmental chamber study." In: S. D. Lee, M. G. Mustafa, and M. A. Mehlman, eds. Advances in Modern Toxicology. Vol. V. Princeton: Princeton Scientific Publishers Inc., 1982: Chap. 9.
5. U. S. Environmental Protection Agency. "Ambient monitoring guidelines for PSD." EPA-450/2-78-019 Environmental Monitoring Systems Laboratory. North Carolina: Research Triangle Park, (1978).
6. E. L. Korn and A. S. Whittemore, "Methods for analyzing panel studies of acute health effects of air pollution," Biometrics 35: 795-802 (1979).
7. R. W. Stacy, E. Seal, Jr., J. Green, et al., "Pulmonary function in normal humans with exercise and temperature-humidity stress," J. Appl. Physiol., 53: 1015-8 (1982).
8. R. J. Knudson, R. C. Slatin, M. D. Lebowitz, et al., "The maximal expiratory flow-volume curve. Normal standards, variability, and effects of age," Am. Rev. Respir. Dis. 113: 587-600 (1976).
9. W.F. McDonnell, D.H. Horstman, M.J. Hazucha, et al., "Pulmonary effects of ozone exposure during exercise: dose-response characteristics." J. Appl. Physiol. 54: 1345-1352 (1983).

TABLE I
SELECTED CHARACTERISTICS OF RUNNERS BY GENDER

	Age in Years	Length of Time Running before study (months)	V _{0₂} Max. ^a	Heart Rate @ Max. (beats/min.	FVC (ml) in lab ^b BTPS	% of Predicted ^c FVC	
males (n=18)	Mean	37.5	45.4	41.8	179	5112	97.08
	S.D.	5.4	21.2	5.4	7.3	440	9.78
females (n=6)	Mean	37.0	69.7	33.4	183	3412	92.78
	S.D.	3.4	67.9	6.8	8.2	687	14.48

^a V_{O_2} max. = maximum oxygen uptake test.

^bBTPS =

Body temperature and ambient pressure for gas saturated with water vapor

^cPredicted values from: Knudson et al.

TABLE II
CONCENTRATIONS OF OTHER SELECTED
POLLUTANTS, MAY-OCTOBER, 1981

	<u>Median</u>	<u>90th Percentile</u>	<u>Maximum</u>
Sulfur dioxide (ppm) 4-7 PM CDT	0.003	0.006	0.010
Nitrogen dioxide (ppm) 4-7 PM CDT	0.006	0.015	0.034
Carbon monoxide (ppm) 4-7 PM CDT	BDL ^a	0.846	2.008
Fine inhalable particulate mass ($\mu\text{g}/\text{m}^3$) 7 AM-7 PM CDT	10.000	24.000	55.000

^aBDL = below detectable limit, for $\text{SO}_2 < 0.002$ ppm, for $\text{NO}_2 < 0.004$ ppm,
for CO < 0.5 ppm.

TABLE III
AVERAGE^a OZONE, TEMPERATURE AND RELATIVE HUMIDITY
4-7 PM PERIOD, MAY-OCTOBER, 1981

	Average	Standard deviation	Minimum	Maximum	Number of runs
Ozone (ppm)	.047	.029	.004	.135	544
Temperature (°F)	85.0	5.2	64.4	100.4	544
Relative humidity (%)	62.6	9.8	37.0	88.0	544

^aAverages are based on the weighted maximum estimated exposures calculated for each runner during each run.

TABLE IV
SUMMARY RESULTS FOR THE CORRELATION^a
OF TEMPERATURE, RELATIVE HUMIDITY AND OZONE,
MAY-OCTOBER, 1981, FOR 24 RUNNERS

	Ozone/Temp	Ozone/ Humidity	Temp Humidity
Median	-.06	-.423	.037
# with positive correlations	9	0	13
Lowest negative correlation	-.241	-.587	-.764
Maximum correlation	.479	-.046	.365

^aCorrelation coefficients are based on the weighted maximum exposures calculated for each runner during runs.

TABLE V

REGRESSION COEFFICIENTS FOR THE DIFFERENCE IN PULMONARY FUNCTION
(post-run 15 minutes minus pre-run)
AND THE WEIGHTED MAXIMUM OZONE CONCENTRATION
FOR THE GROUP OF 24 RUNNERS

Pulmonary function tests	Average Intercept	Average Regression Coefficient (B)	Standard Deviation of the Average B	t-test	Significance of B (p)
FVC (ml)	.002	-0.1	0.163	-0.61	0.55
FEV _{1.0} (ml/sec.)	.103	-0.4	0.163	-2.45	0.03
FEF _{25-75%} (ml/min.)	19.337	-56.9	21.964	-2.59	0.02
FEF _{2-1.2} (ml/min.)	8.091	-142.5	54.889	-2.69	0.02

TABLE VI

PARTIAL REGRESSION COEFFICIENTS^a OF THE DIFFERENCE IN PULMONARY FUNCTION
(post-run 15 minutes minus pre-run)

AND THE WEIGHTED MAXIMUM OZONE CONCENTRATION
ADJUSTED FOR TEMPERATURE AND RELATIVE HUMIDITY
FOR THE GROUP OF 24 RUNNERS

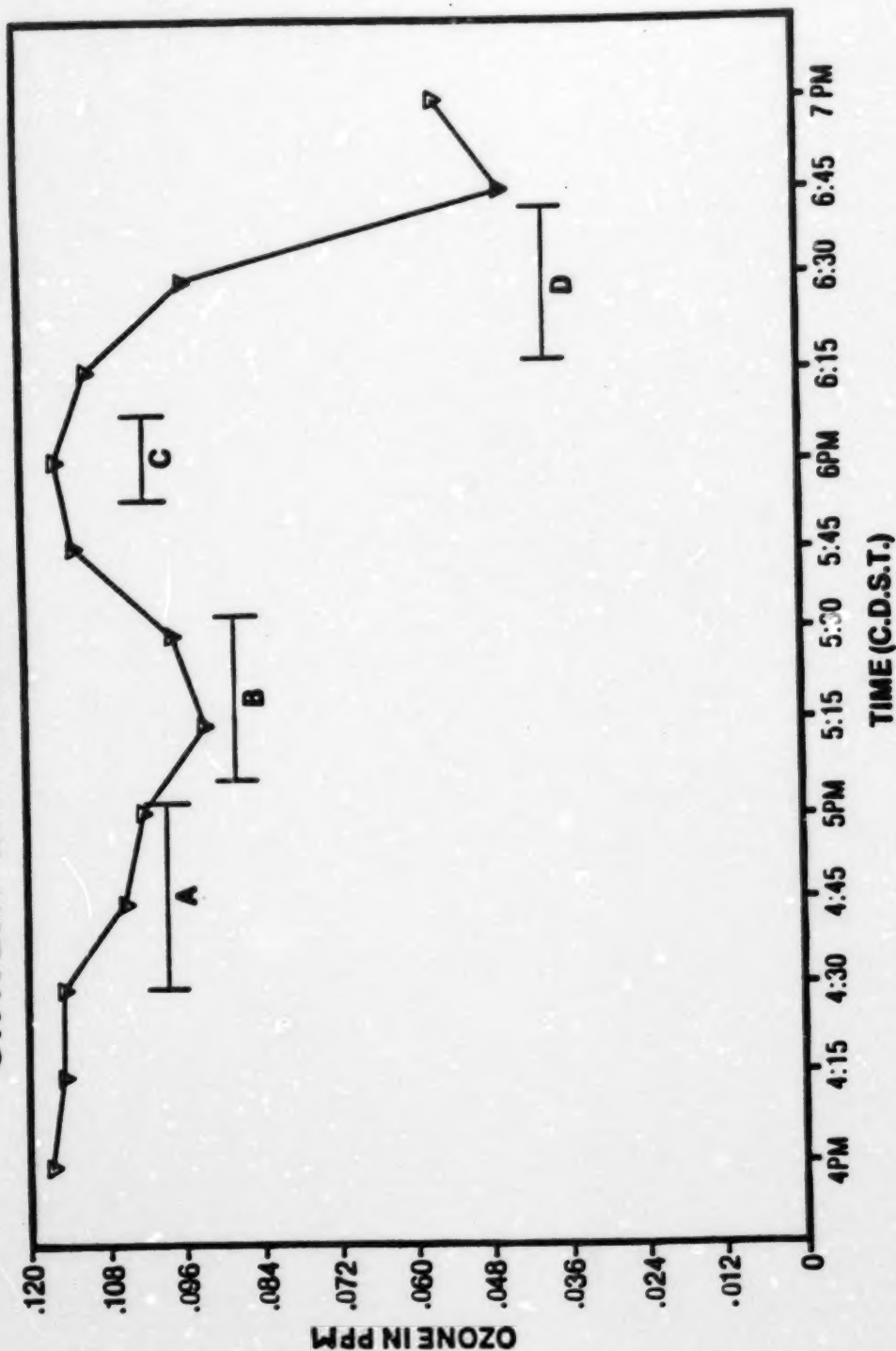
Pulmonary Function Tests	Average Weighted Regression Coefficient	Standard Deviation of the Weighted B	95% Confidence limits of B Score		Z of B	Significance ^b (p)
FVC (ml)	0.14	0.22	-0.29	0.57	0.66	0.51
FEV _{1.0} (ml/sec.)	-0.07	0.19	-0.44	0.30	-0.36	0.72
FEF _{25-75%} (ml/min.)	-24.59	23.49	-70.60	21.45	-1.05	0.29
FEF _{2-1.2} (ml/min.)	-64.50	61.75	-185.50	56.53	-1.04	0.30

^aKorn-Whittemore⁶ weighted analysis technique, random effects model.

^bp values are based on two-sided tests.

Figure 1

VARIATION IN OZONE CONCENTRATION (15 minute averages) ON A DAY WITH RUNNERS* PERFORMING



*A, B, C and D refer to selected individual runners and show actual run times that day (6/17/81).

Figure 2
CALCULATION OF INDIVIDUALLY WEIGHTED
15 MINUTE AVERAGES OF MAXIMUM OZONE
EXPOSURE DURING RUN

TIME	4:30PM	5	5:30	6	6:30	7PM				
OZONE (ppm)	.075	.074	.075	.08	.095	.096	.11	.095	.09	.07
RUNNERS		22 min.				30 min.				
		:-----:				:-----:				
		15:08	5:30		6:13	6:43				
		✓			✓					
		✓			✓					
		✓			✓					
		✓			✓					
		✓			✓					
CALCULATION		15min X .08ppm				(2min X .11ppm)+(13min X .095ppm)				
		-----				-----				
		15min				15min				
EXPOSURE ESTIMATE		= .08 ppm				= .097 ppm				

Figure 3

SCATTER PLOT OF THE REGRESSION COEFFICIENTS FOR
CHANGE IN $FEV_{1.0}$ AT 15 MINUTES POST RUN WITH OZONE
EXPOSURE UNADJUSTED AND ADJUSTED FOR
TEMPERATURE AND RELATIVE HUMIDITY AND A LINE
REPRESENTING IDENTICAL VALUES BEFORE AND AFTER
ADJUSTMENT

